A low-energy effective model for quantum chromodynamics*

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In a low-energy effective model for quantum chromodynamics, we studied the real-time dynamics in a linear sigma model coupled to two light quark flavors. We found a dramatic amplification of quark production in the presence of highly occupied bosonic quanta for weak as well as strong effective couplings. For the mesonic sector we confirmed the existence of a turbulent scaling regime, known from previous studies of purely mesonic effective theories. Using for the first time real-time lattice field theory techniques with dynamical fermions in 3+1 dimensions, we demonstrated the failure of standard semiclassical descriptions based on the Dirac equation with a homogeneous background field to capture these phenomena [1].

To get a more detailed picture of quark dynamics and to test our approach we considered the range of validity of different methods: lattice simulations with male/female fermions, the mode functions approach and the quantum 2PI effective action with its associated kinetic theory. For strongly coupled quarks we found a rapid approach to a Fermi-Dirac distribution with time-dependent temperature and chemical potential parameters [2], while the mesons are still far from equilibrium.

We employed and improved the available real-time lattice techniques in order to investigate fermion–anti-fermion production in gauge theory, considering $1 + 1$ dimensional QED. In this non-perturbative approach the full quantum dynamics of fermions is included while the gauge field dynamics can be accurately represented by classical-statistical simulations for relevant field strengths. We computed the non-equilibrium time evolution of gauge invariant correlation functions implementing 'low-cost' Wilson fermions. Introducing a lattice generalization of the Dirac-Heisenberg-Wigner function, we recovered the Schwinger formula in $1 + 1$ dimensions in the limit of a static background field. We discuss the decay of the field due to the backreaction of the created fermion–anti-fermion pairs and apply the approach to strongly inhomogeneous gauge fields [3]. The latter allows us to discuss the striking phenomenon of a linear rising potential building up between produced fermion bunches after the initial electric pulse ceased and its decay, a phenomenon closely related to string-breaking in quantum chromodynamics.

Following these investigations we focused on the real-time dynamics of string breaking in quantum electrodynamics in one spatial dimension. A two-stage process with a clear separation of time and energy scales for the fermion–antifermion pair creation and subsequent charge separation leading to the screening of external charges was found [4]. Going away from the traditional setup of external static charges, we established the phenomenon of multiple string breaking by considering dynamical charges flying apart.

References

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